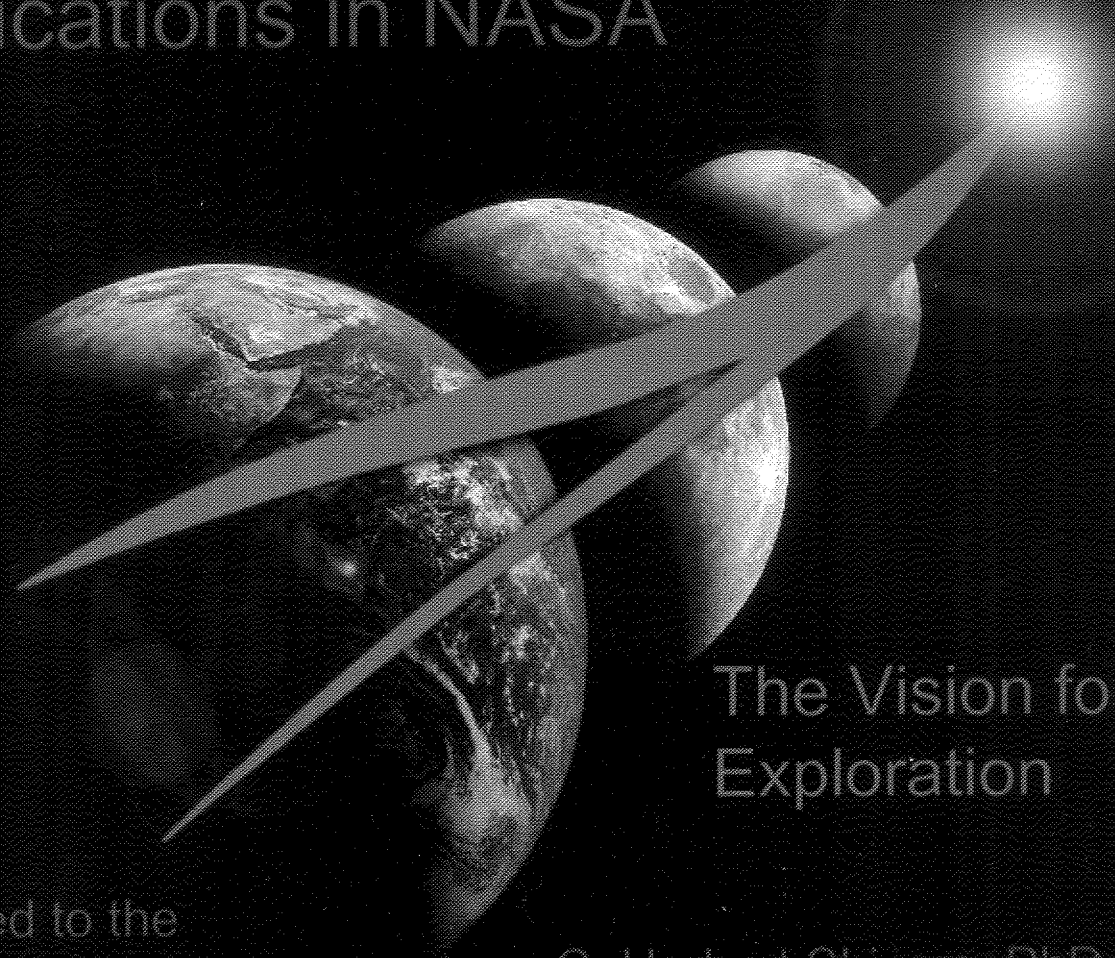
Source of Acquisition
NASA Marshall Space Flight Center

Industrial and Systems Engineering Applications in NASA

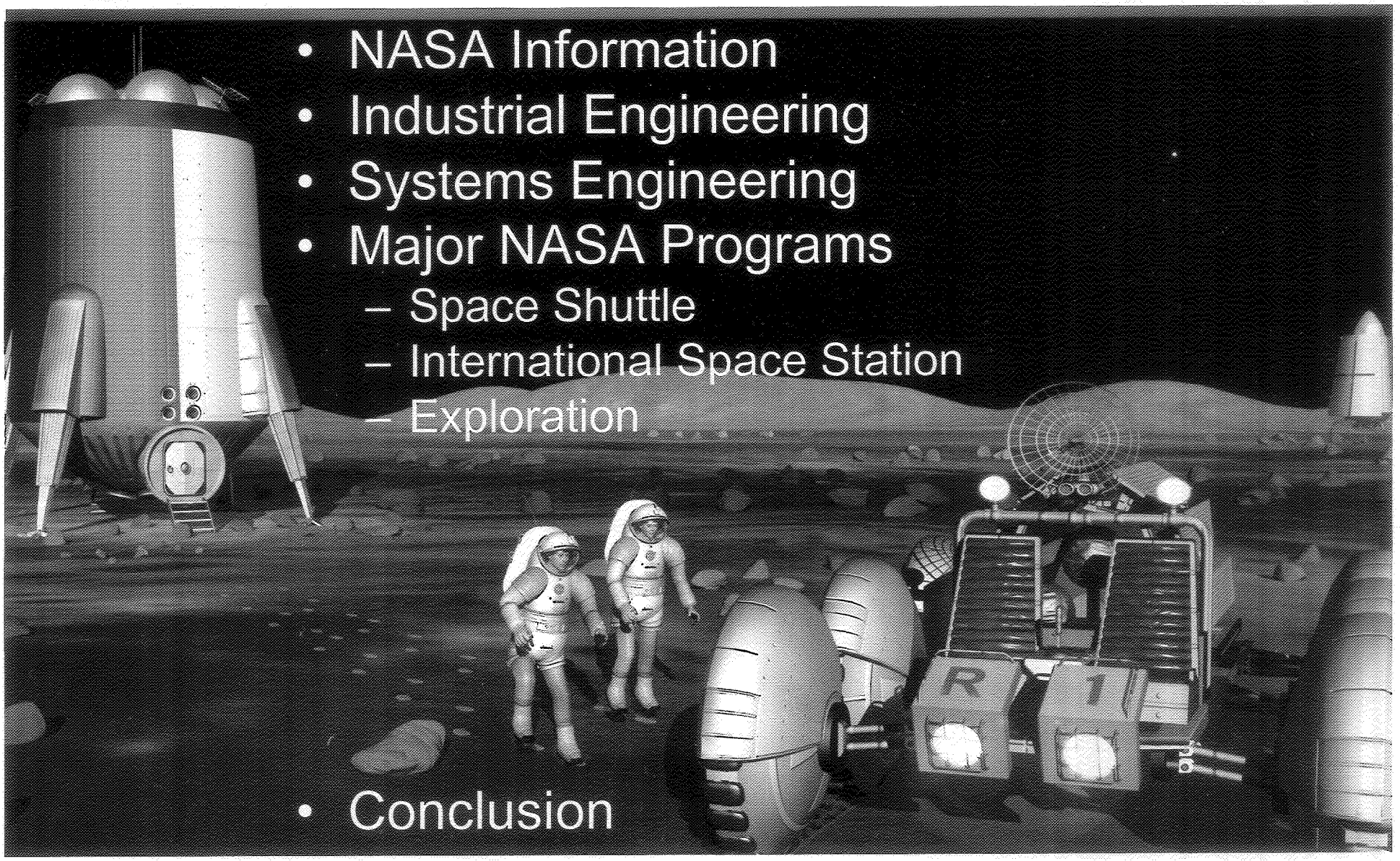


The Vision for Space Exploration

Presented to the
1st International Congress of Industrial and Systems Engineering
Morelia, Michoacán, Mexico
September 2006

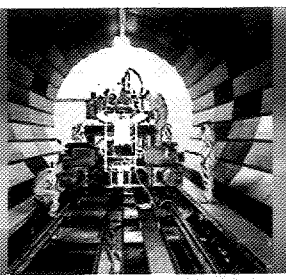
C. Herbert Shivers, PhD, PE, CSP
Assistant to the Director of Engineering
NASA/Marshall Space Flight Center

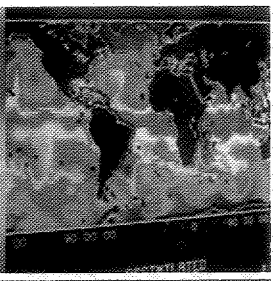
AGENDA

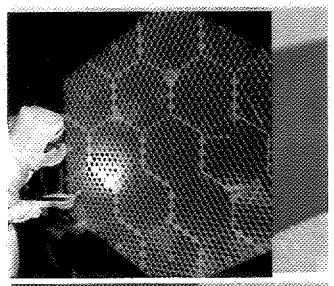


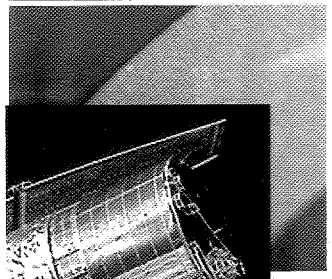
- NASA Information
- Industrial Engineering
- Systems Engineering
- Major NASA Programs
  - Space Shuttle
  - International Space Station
  - Exploration
- Conclusion

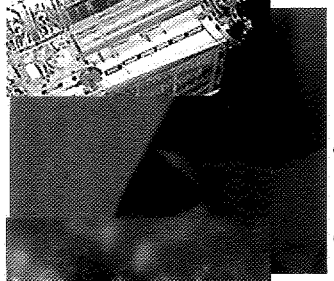
National Vision for Space Exploration

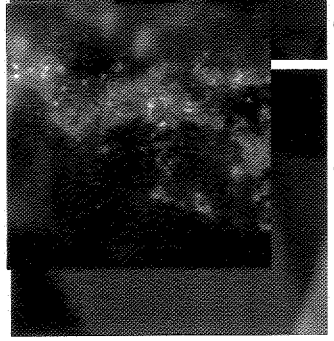






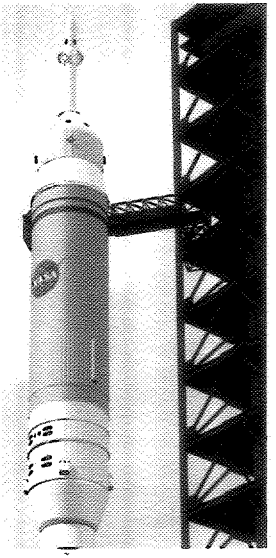




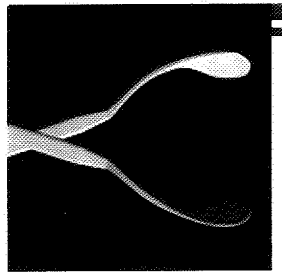


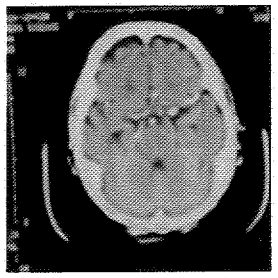
NASA's strategic goals

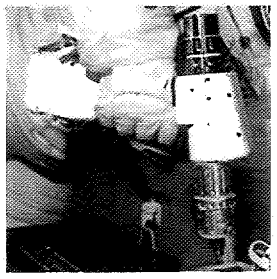
- Fly the space shuttle as safely as possible until its retirement.
- Complete the International Space Station, accommodating international partner commitments and human exploration.
- Develop a balanced overall program of science, exploration, and aeronautics consistent with the new focus on human exploration.
- Bring a new Crew Exploration Vehicle into service.
- Encourage partnerships with the emerging commercial space sector.
- Return to the moon and make it a base for later missions to Mars and beyond.

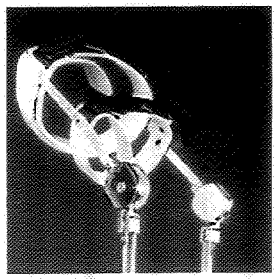


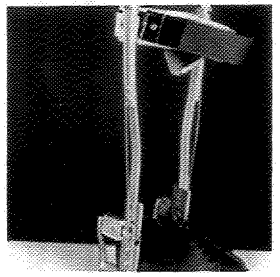
Improving Life on Earth







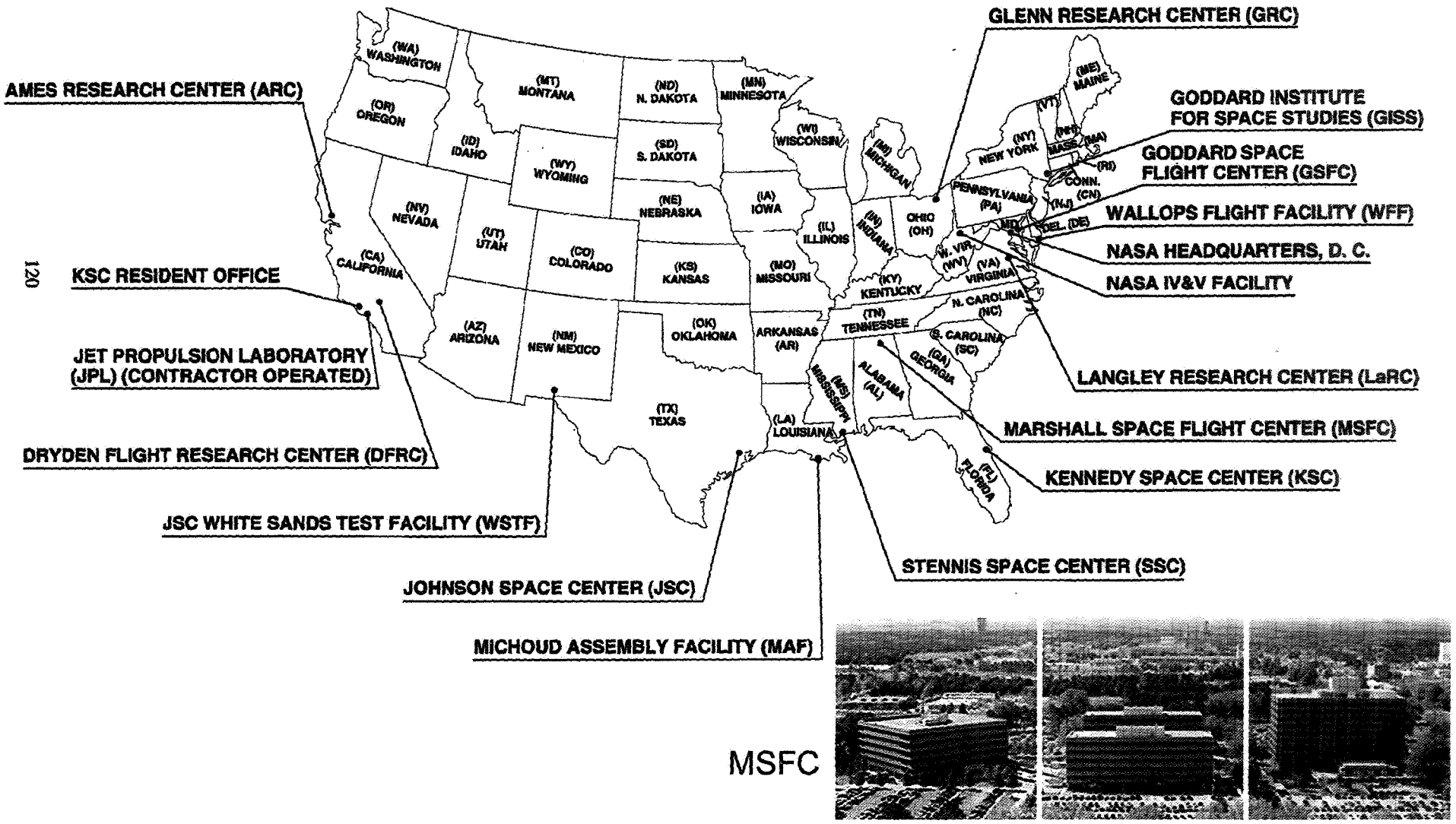




More than 1,000 consumer products and services are built on NASA-developed technologies

- Smoke detectors
- Solar water heaters
- Cordless tools
- Satellite-based telephone, TV, and GPS
- Video enhancement system for law enforcement
- Selectively lockable knee brace
- "Smart" obstetrical forceps
- Compact rescue shears
- Eye health screening system
- Powerful medical X-ray lens system
- Many, many more ...

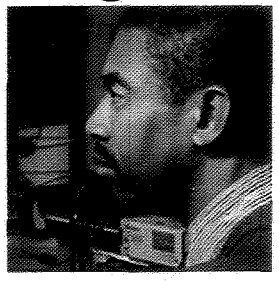
NASA LOCATIONS

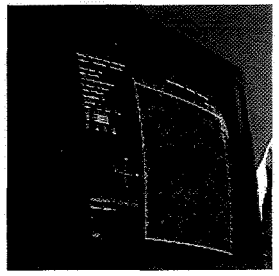


MSFC

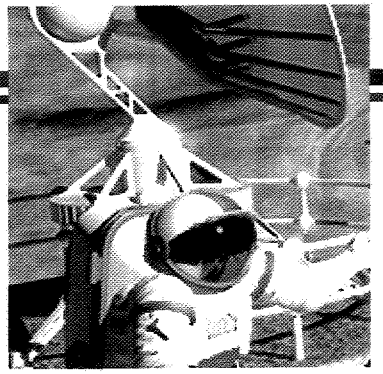
Industrial Engineering

- **Major areas of specialization**
  - **Engineering economics and decision analysis**
  - **Human factors (human-machine/computer interaction)**
  - **Manufacturing systems**
  - **Optimization**
  - **Production, distribution, and material handling**
  - **Statistics**
  - **Stochastic systems**





IE Astronauts



- Nancy J. Currie PhD (Industrial Engineering) from University of Houston
- Michael J. Massimino B.S. Industrial Engineering, Columbia University
- Rex Walheim master's degree in industrial engineering from the University of Houston

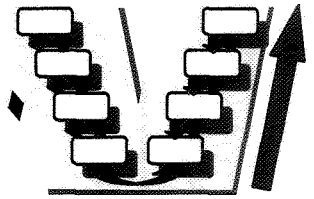
Kennedy Space Center

- **The Space Shuttle Processing Department, Expendable Launch Vehicles Directorate, International Space Station Department, and Safety Health and Independent Assessment Department generally accept persons majoring in:**
  - **Electrical Engineering**
    Mechanical Engineering
    Industrial Engineering
    Computer Engineering
    Aerospace Engineering
    Other Majors as needed

- **The Workforce and Diversity Management department generally accepts persons majoring in:**
  - **Human Resources Management**
    Industrial Engineering
    Management
    Public Administration
    Other majors as needed

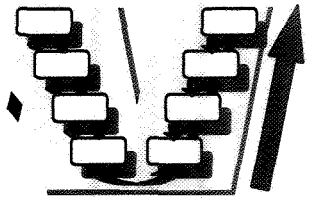
Systems Engineering (SE)

- The SE effort spans the whole system lifecycle
  - focuses on defining customer needs and required functionality early in the development cycle
  - requirements documentation
  - design synthesis and system validation



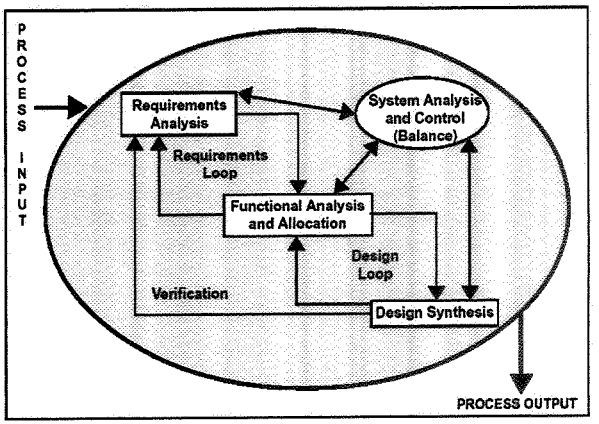
- Considers the complete problem:

Cost & Schedule	Performance Engineering
Environment	Training
Design and Development	Operations and Maintenance
Information Assurance	Test & Evaluation
Manufacturing and Deployment	System Disposal

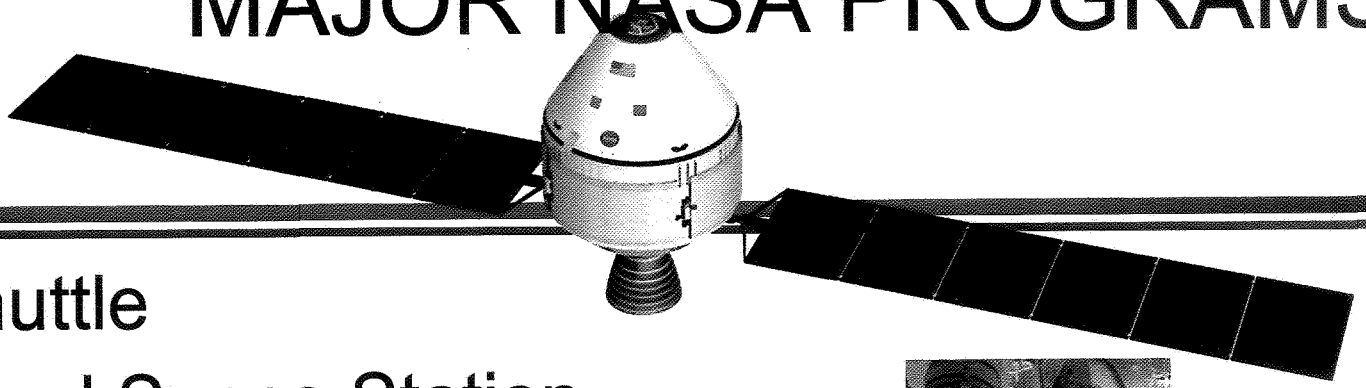


Example Systems Engineering Methods and Tools

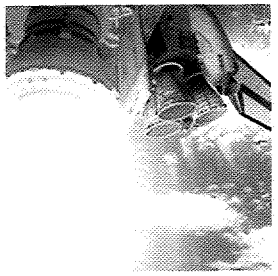
- Requirements capture
- Requirements analysis
- Systems architecture and design
- Functional analysis
- Interface design and specification
- Communications protocol design and specification
- Simulation and modeling
- Verification and validation/acceptance testing
- Fault modeling

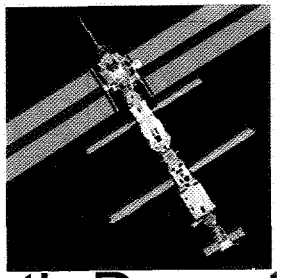


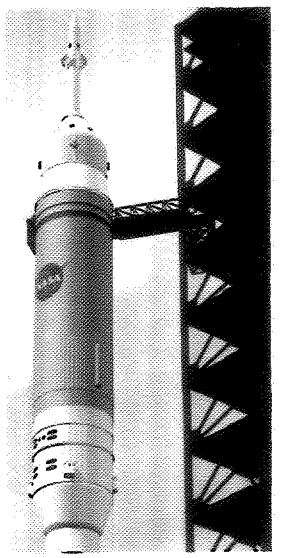
MAJOR NASA PROGRAMS

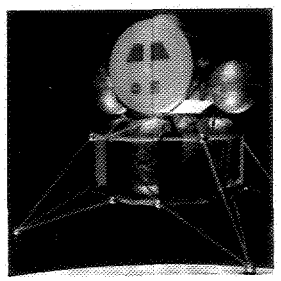


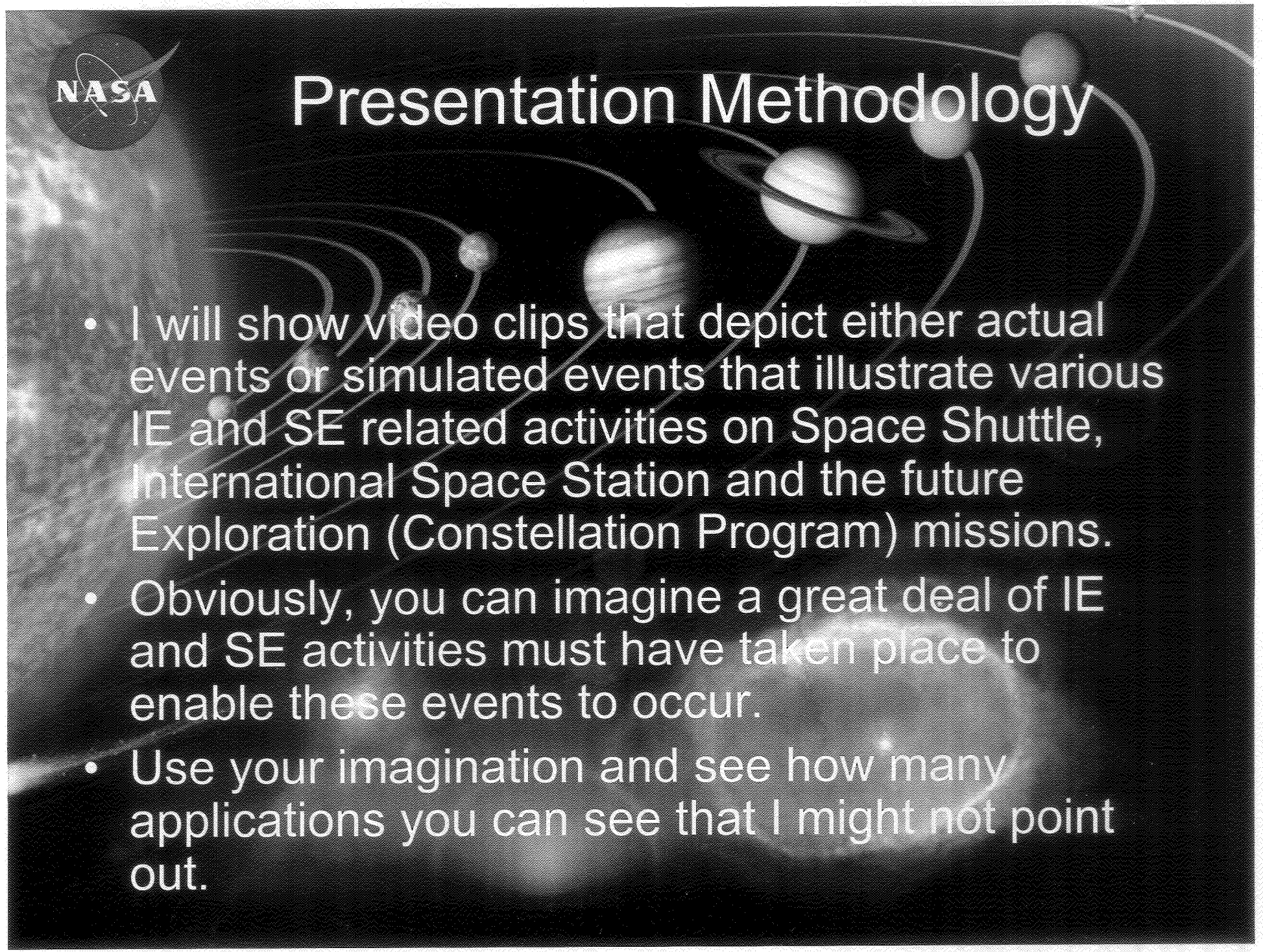
- Space Shuttle
- International Space Station
- Constellation Program (Future)
  - Crew Launch Vehicle
  - Cargo Launch Vehicle
  - Crew Exploration Vehicle
  - Crew Service Module
  - Lunar Surface Access Module, Earth Departure Stage, etc.
  - The Mars Transfer Vehicle and The Mars Descent Ascent Vehicle







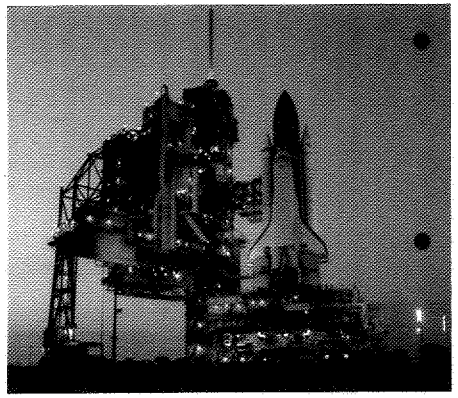




Presentation Methodology

- I will show video clips that depict either actual events or simulated events that illustrate various IE and SE related activities on Space Shuttle, International Space Station and the future Exploration (Constellation Program) missions.
- Obviously, you can imagine a great deal of IE and SE activities must have taken place to enable these events to occur.
- Use your imagination and see how many applications you can see that I might not point out.

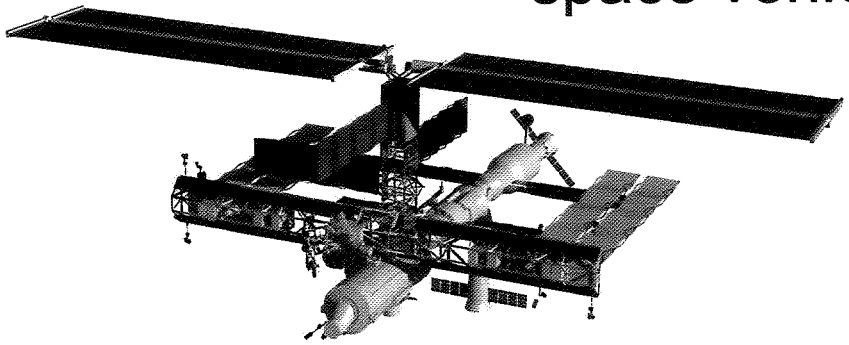
Scenes from NASA Programs

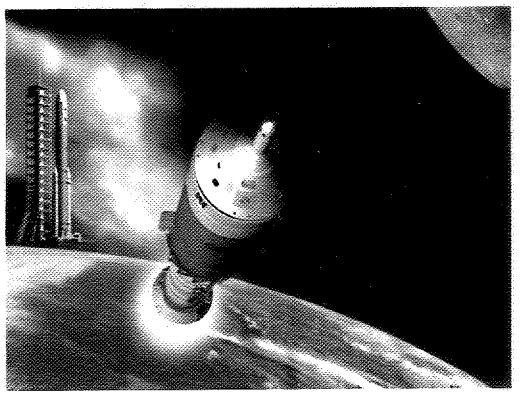


This video shows NASA activities that definitely involve enabling IE and SE functions (ED VIDEO_TS.IFO)

Includes Shuttle docked and undocking with ISS, a contained fluids experiment, working outside and inside ISS

- Some functions illustrated are: Safety, workplace design, tools, planning, maintainability, supportability, logistics planning, human factors and ergonomics, facilities design, and concepts of the new space vehicles

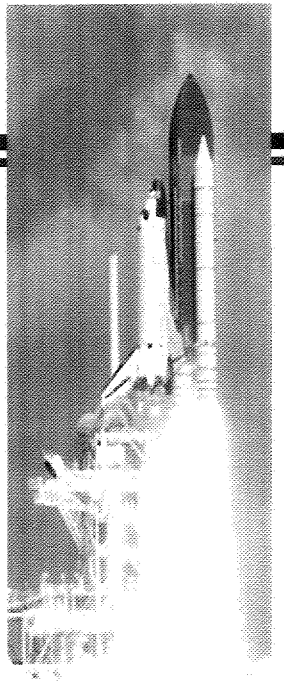


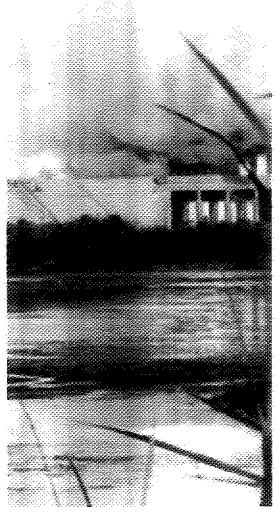


Space Shuttle

- These videos illustrate some Space Shuttle activities that involve industrial and systems engineering activities
  - Launch of STS-121
    - launch sts121_fdh01_3_56.asx
  - Gap filler ground test
    - gap filler test sts114fd8_gapfill2_56.asx
  - External Tank Separation
    - ET sep and ISS crew sts121_fdh01_5_56.asx
  - Baja view
    - BAJA sts113fdh11c_56.asx

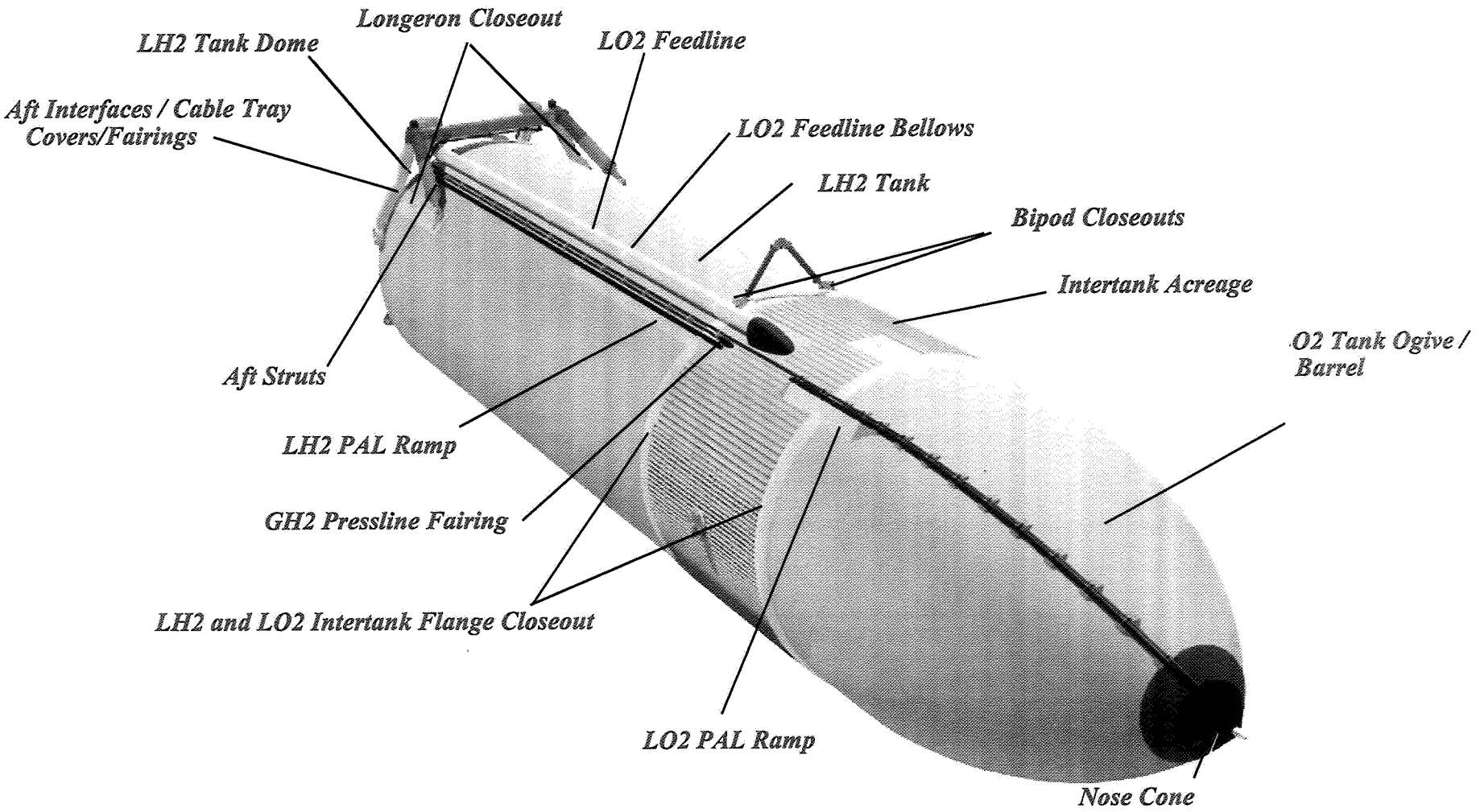
A Shuttle Application



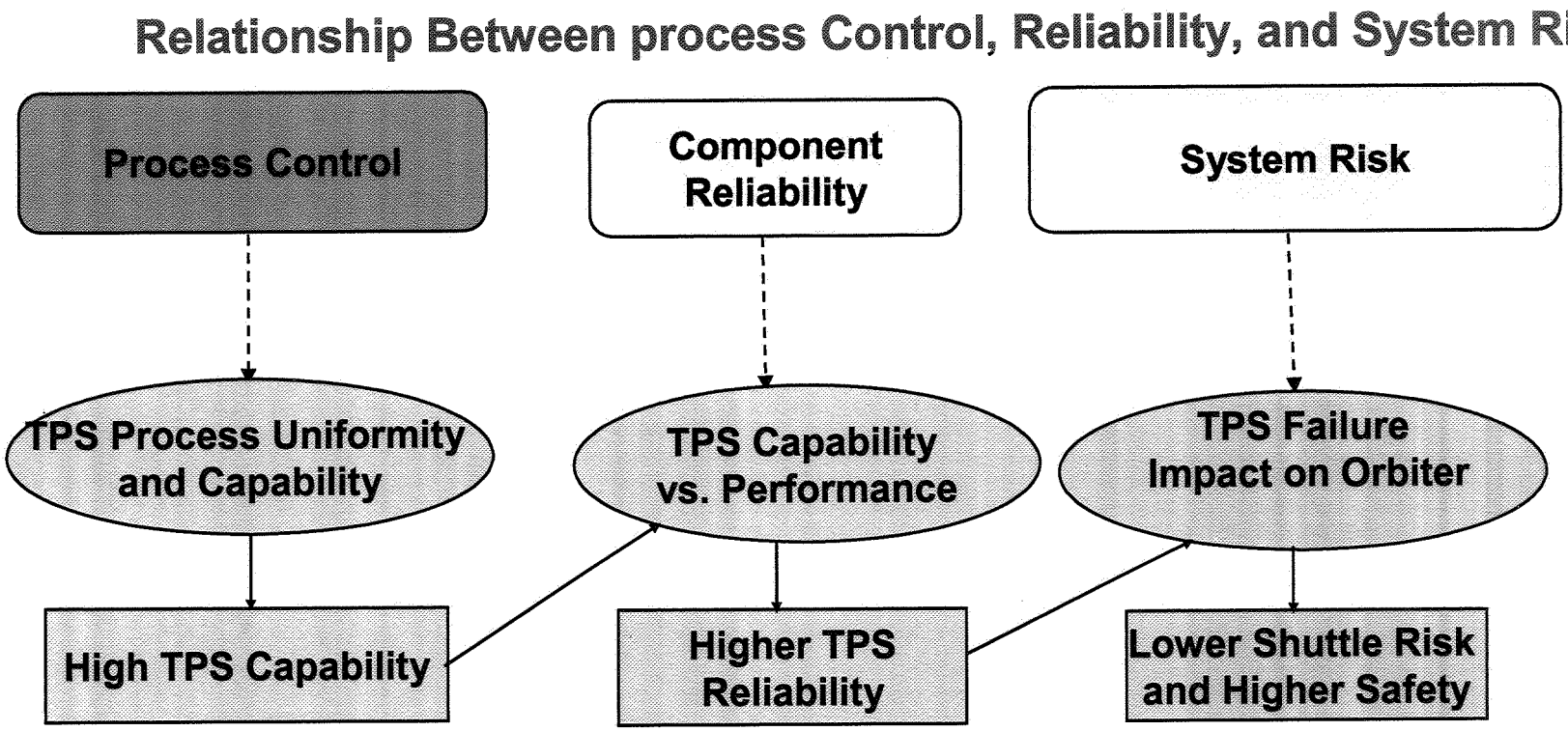


- Developing a safe and reliable space vehicle requires good design and manufacturing, or "design it right and build it right"
- Inadequate process control could result in low quality which leads to low reliability and high system risk
- The difficulties and sensitivities of the External Tank Thermal Protection System (TPS) manual spray process demonstrate the impact of process control on component reliability and system risk
- The TPS is applied to the ET to maintain cryogenic propellant quality, minimize ice/frost formation, and protect the structure from ascent, plume, and re-entry heating

Thermal Protection System Overview

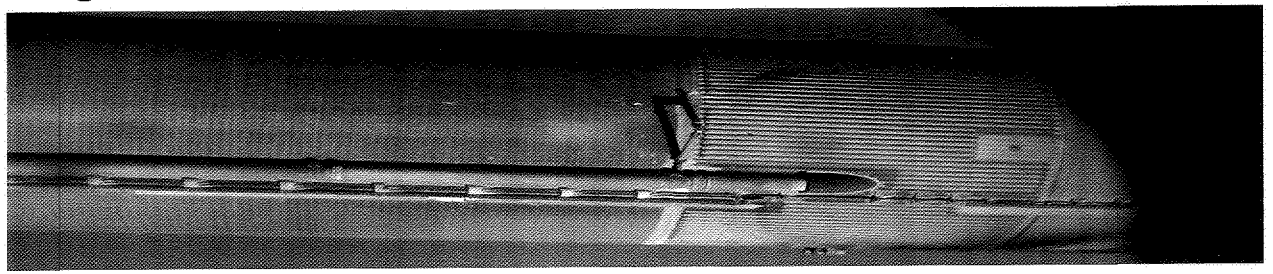


Process Control, TPS Reliability, and System Risk



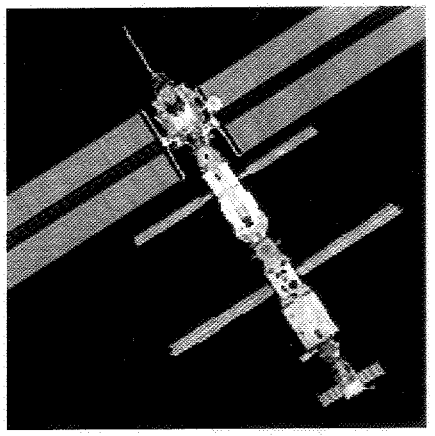
TPS Process control

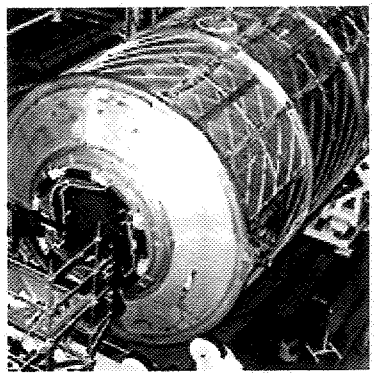
- Improved process/design
- Conducted verification and validation testing to understand and characterize the process variability and process capability
- Evaluated process pre-control charts for process readiness
- Evaluated process capability for meeting the specification
- Evaluated process control for process uniformity
- Statistical evaluation of the data showed that significant improvements were made in process uniformity and process capability, including significant reduction in the coefficient of variation (COV) of the process critical output parameters (e.g. void frequency and void sizes)
- Void characterization was still difficult because of limitation of the data and lack of good definition of the right tail of the data distribution



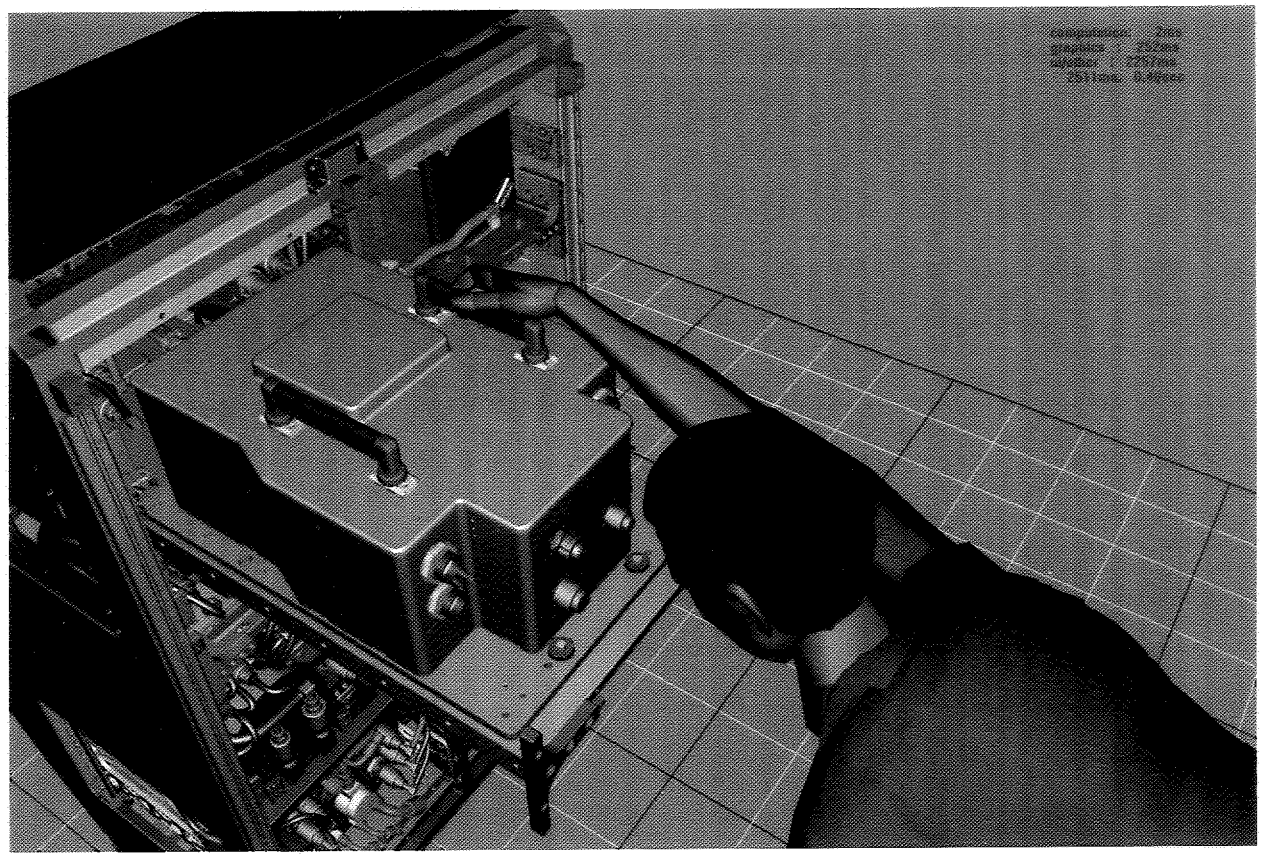
International Space Station Applications

- ISS Assembly Sequence
  - ISS_Assembly_Sequence.asx
- P3/P4 Truss Handling at KSC
  - truss segment sts 115 P3 P4 video.asx
- Human Research Facility Installation
  - HRF install 114_fdh06_clip3_56.asx
- Cargo movement from MPLM to ISS
  - Inside Destiny 114fd06fdh_1_56.asx
- Attaching MPLM to Unity
  - mplm to unity sts121_fdh04_01_56.asx
- Spacewalk over BAJA
  - spacewalk baja 114_fdh05_clip3_56.asx

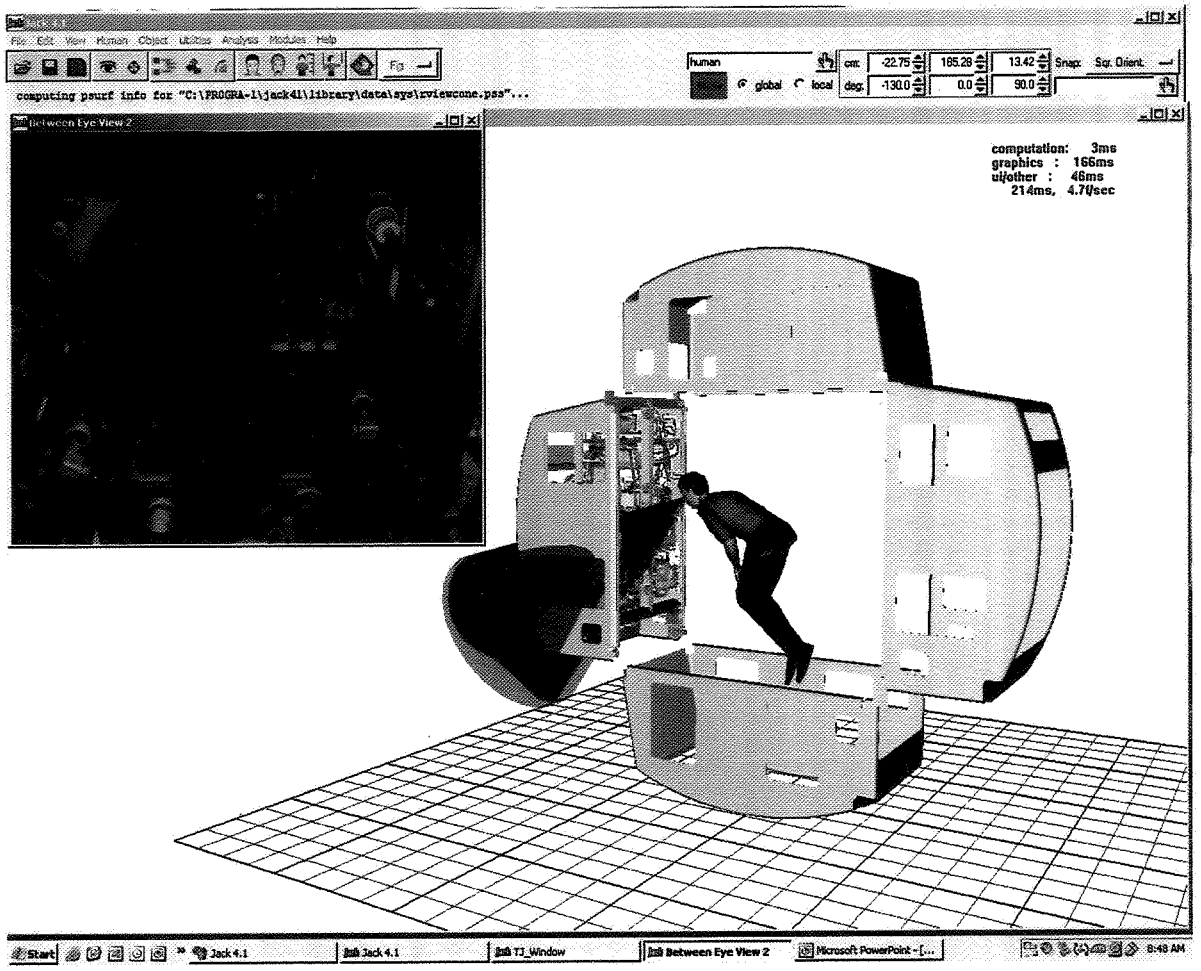




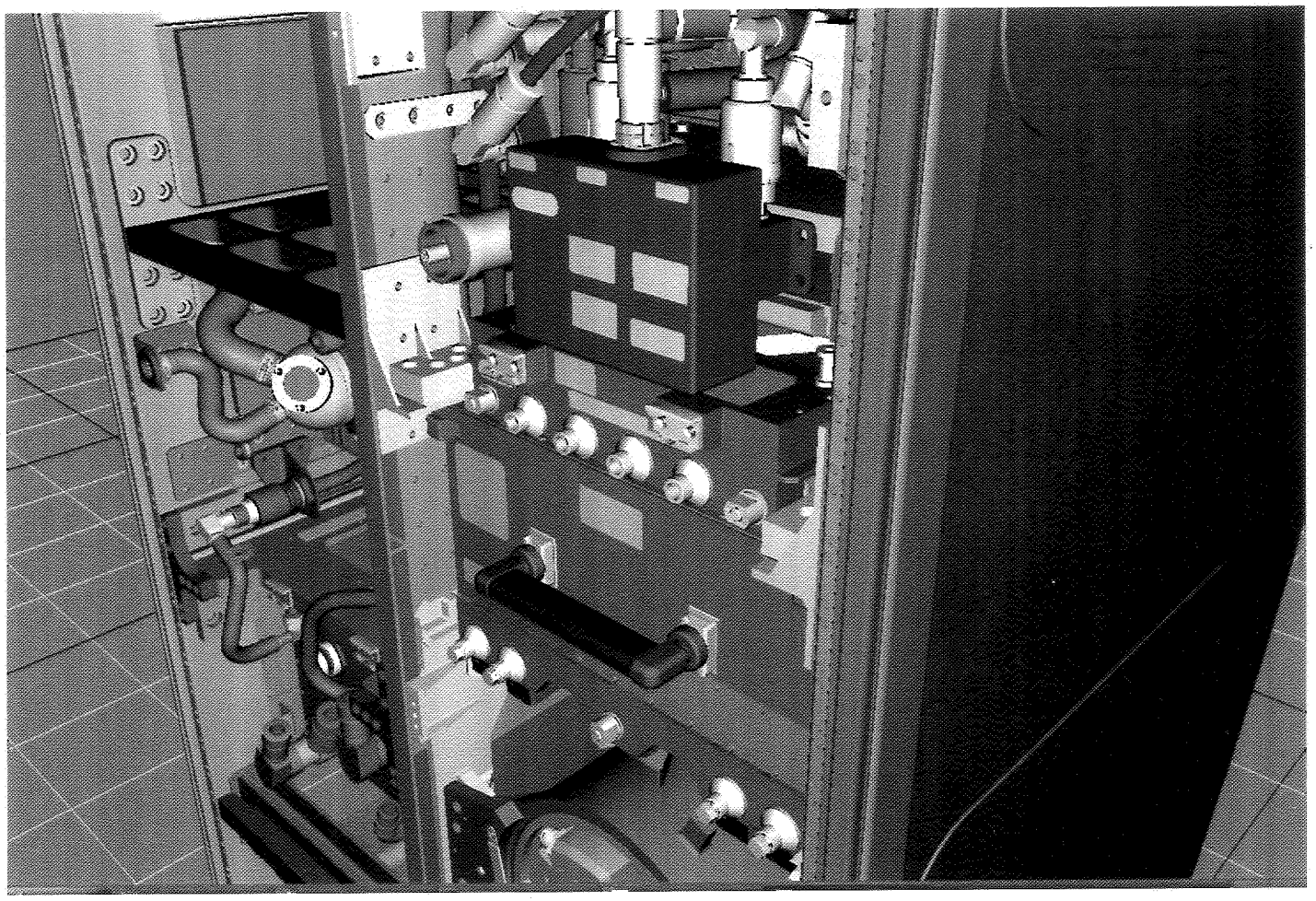
Human Factors Analysis for Rack Maintenance



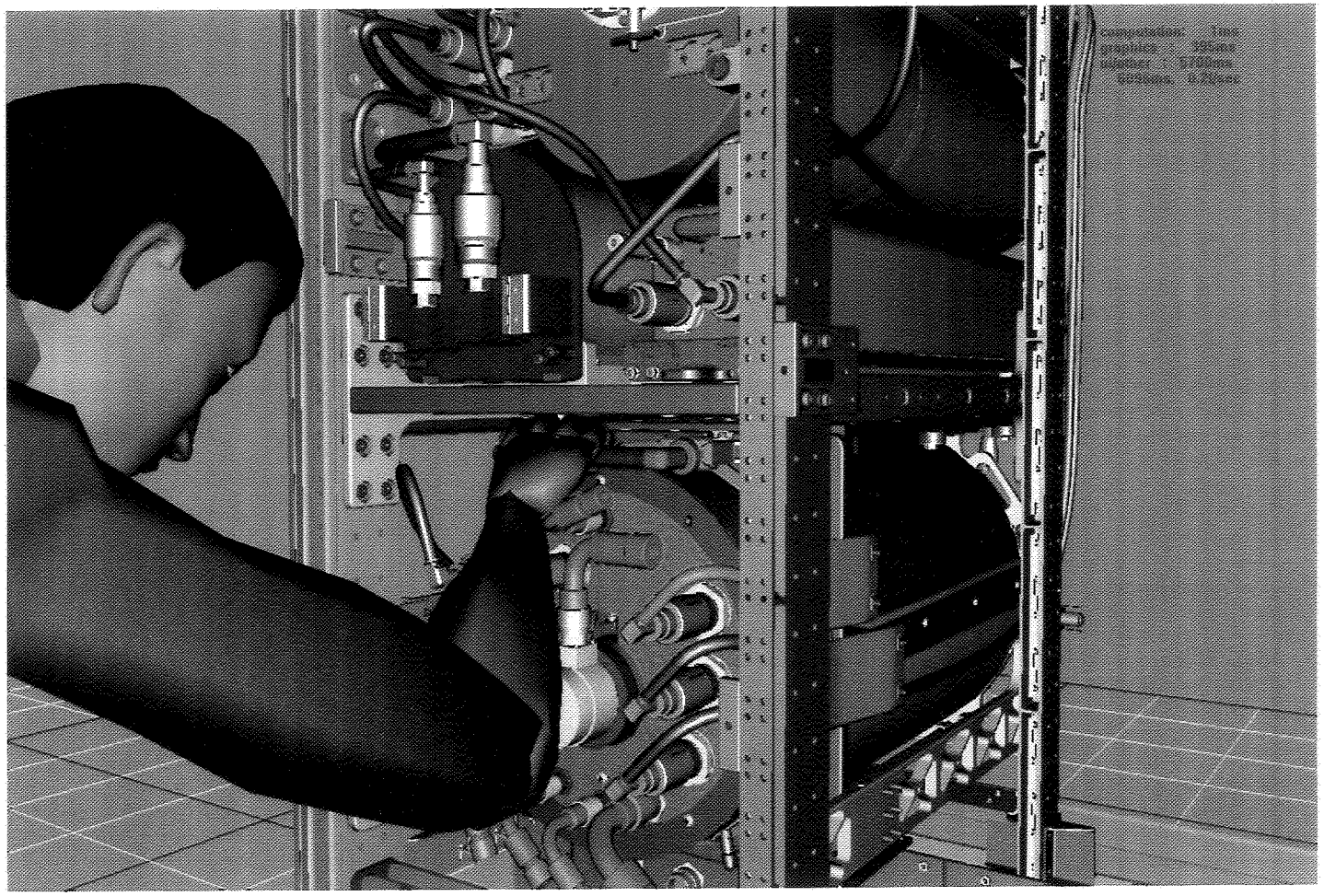
Analysis of Crew Visibility into Rack

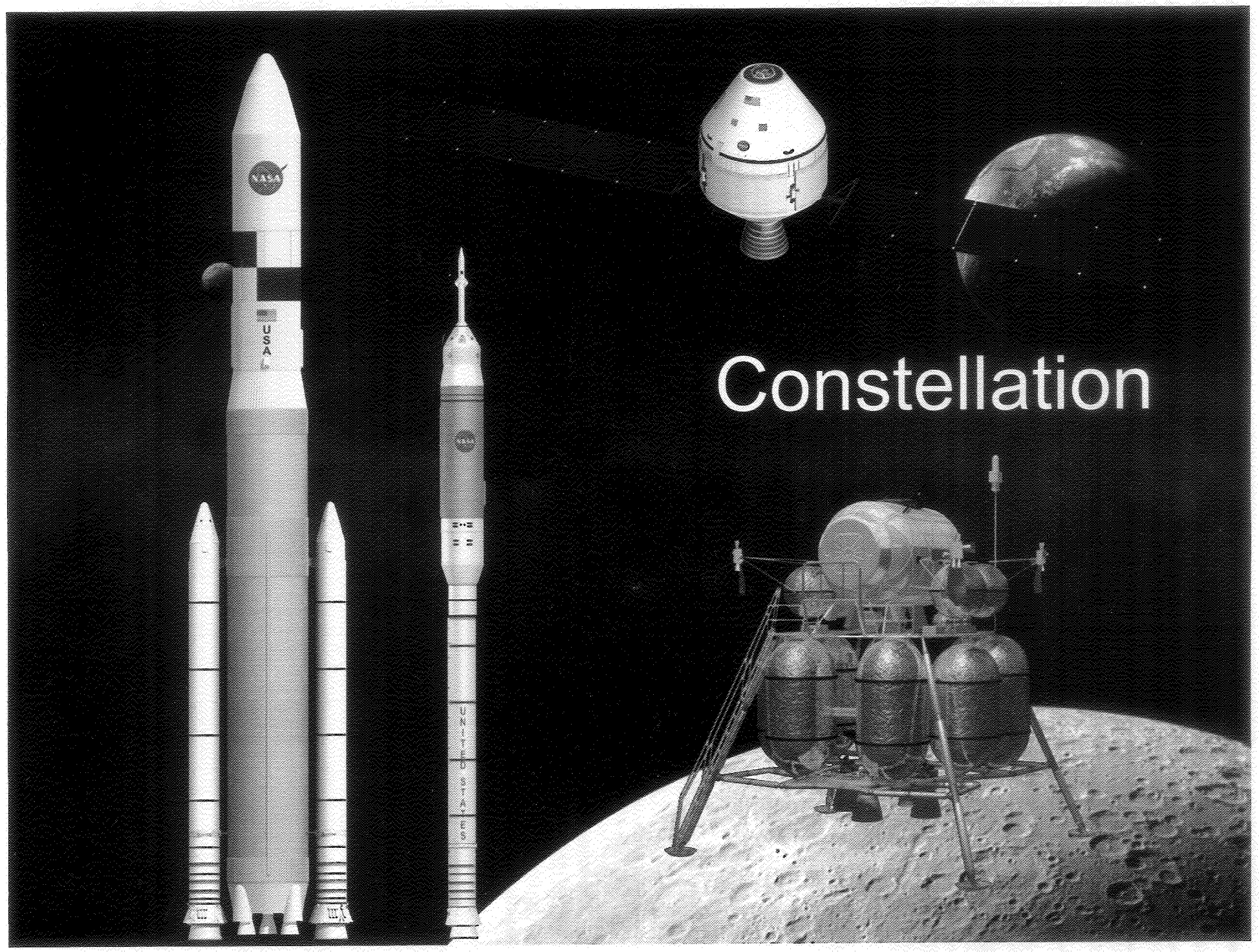


Internal Rack Clearance Analysis



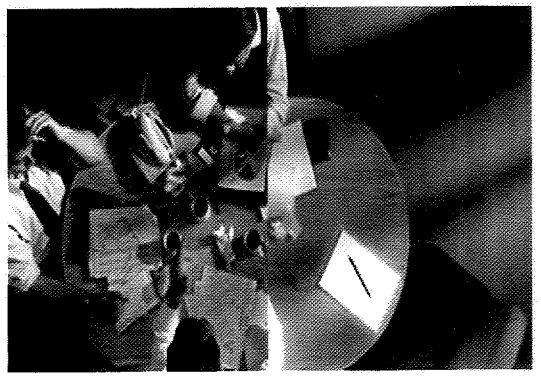
Hand Entrapment Analysis



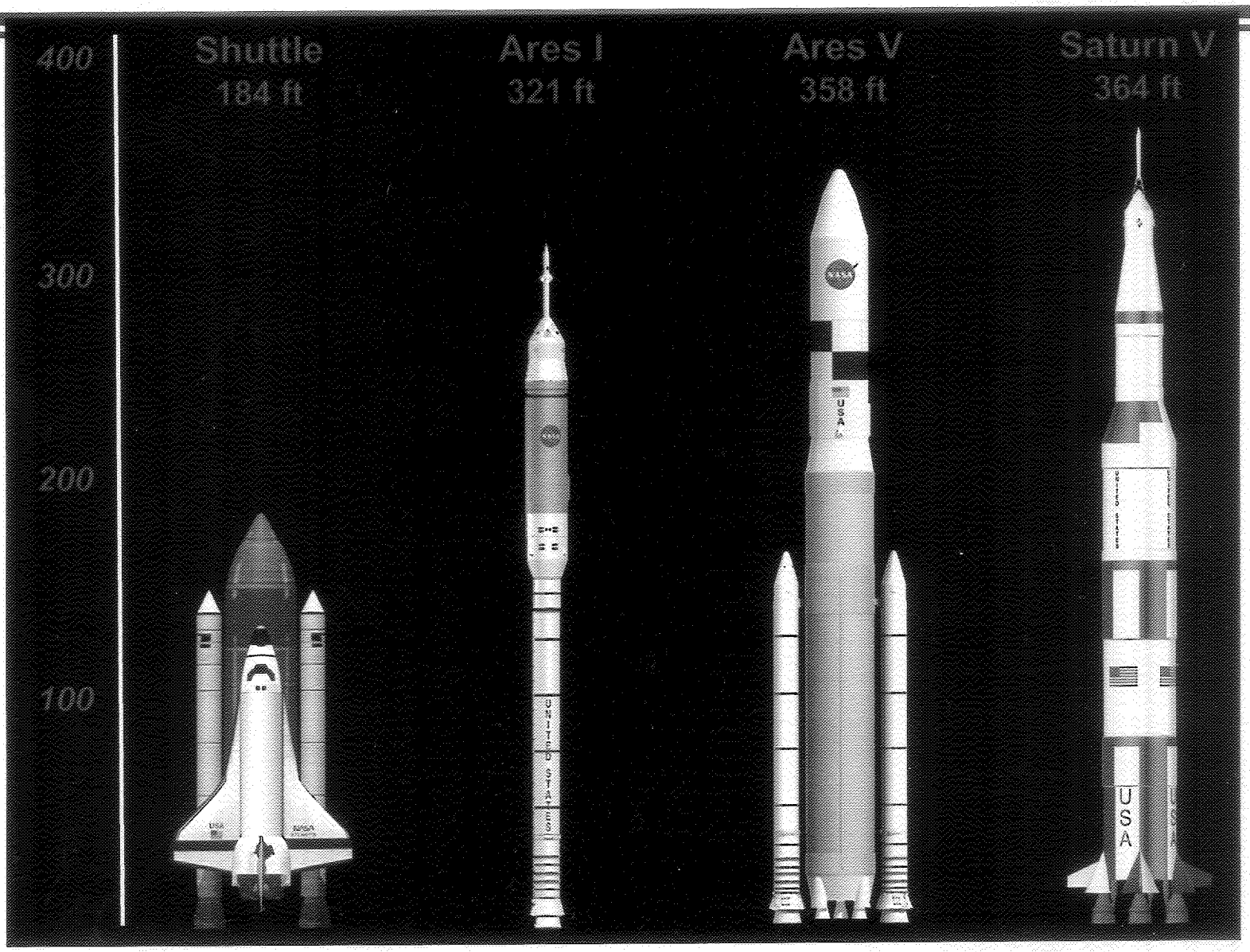

Constellation

Constellation Applications

- ...developing a discrete-event simulation model to estimate the total cost of accomplishing NASA's defined set of missions
- Crew Launch Vehicle:
  - Identifying top operations cost drivers & mitigation strategies
  - Reducing vehicle recurring cost by injecting operability into design

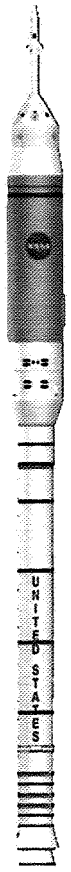


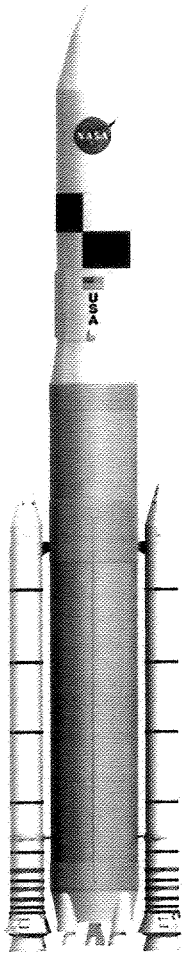
Launch Vehicle Comparison



Ares Vehicles

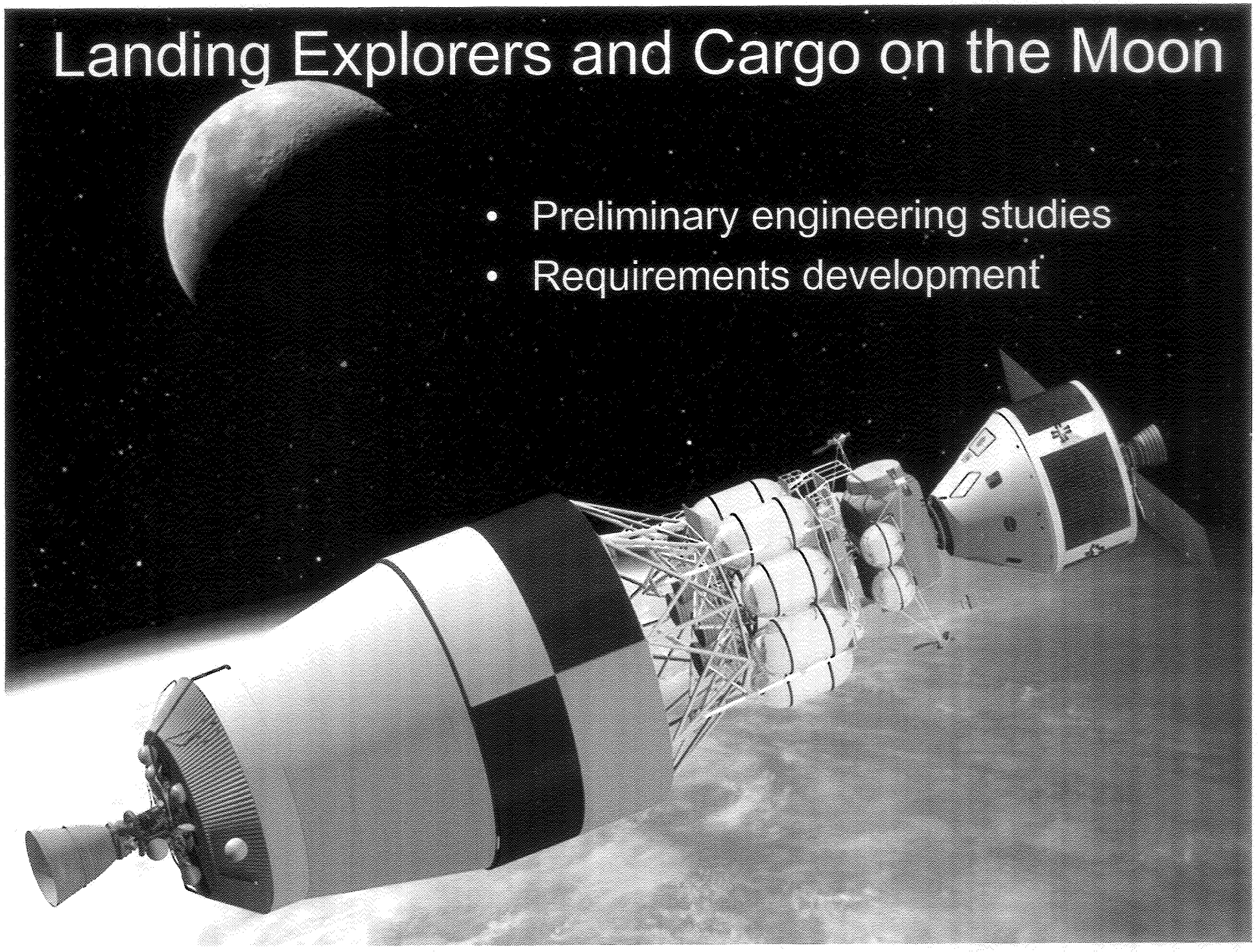
- Notice the various activities mentioned or shown in the following video: (CX VIDEO_TS.IFO)
  - Long term resources planning
  - Project management
  - Design and test
  - Modeling and simulation
  - System requirements analysis and review
  - Design analysis
  - Transition from design to production
  - Facility layout



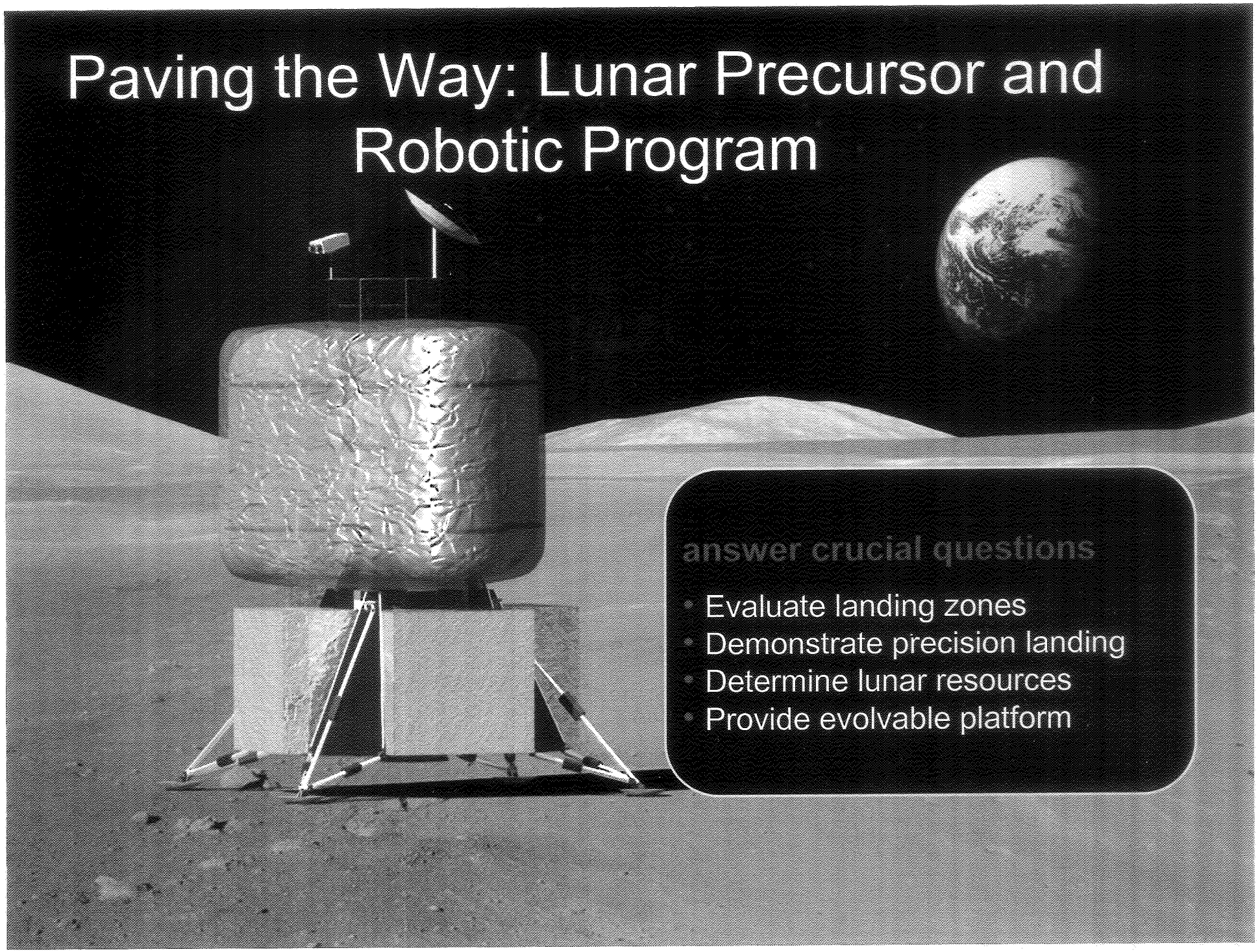


Landing Explorers and Cargo on the Moon

- Preliminary engineering studies
- Requirements development



Paving the Way: Lunar Precursor and Robotic Program

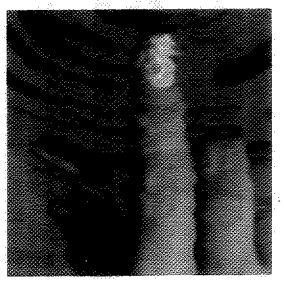


answer crucial questions

- Evaluate landing zones
- Demonstrate precision landing
- Determine lunar resources
- Provide evolvable platform

HFE Simulations for CLV

- Transporting CLV Upper Stage by barge from Michoud Assembly Facility to Stennis Space Center (HFE UPDATED_MAF_USTransportation)
- Lunar Lander Ascent Module Human Engineering Assessment to determine whether the Ascent Module provided sufficient room for two Crewmembers to don and doff two Mark III space suits (HFE LunarLanderII)
- Concept for crewmember to access the Instrument Unit through the provided hatch for component maintenance (HFE InstrumentUnit_Maintenance)
- Collaboration work for the Vehicle Assembly and Integration task showing the integration of the CLV and Human Factors concept for crew access to attach points between the First Stage and Upper Stage (HFE vi&a)

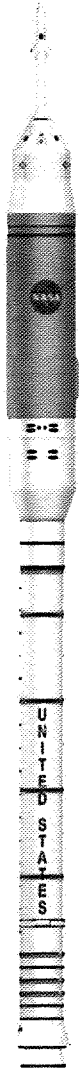


Ares I and V Launch Vehicles

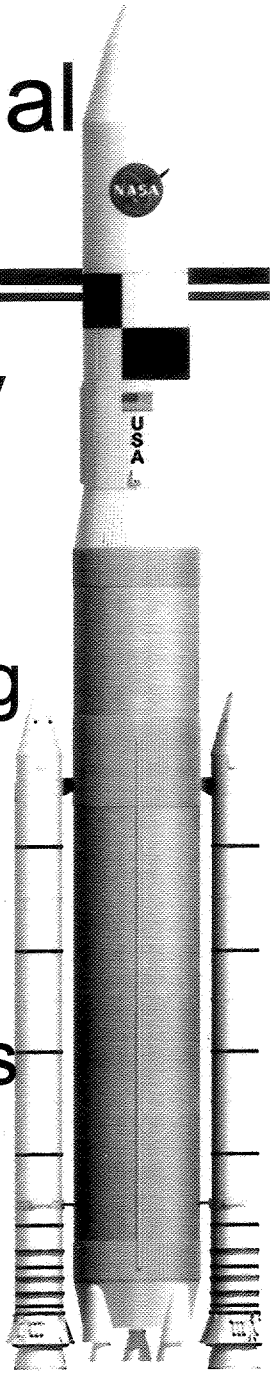
Ares 1 and Ares V development

- Systems engineering and integration
- Safety and mission assurance
- First stage design and upper stage engine development and contracts management
- Upper stage design, development, testing, and evaluation

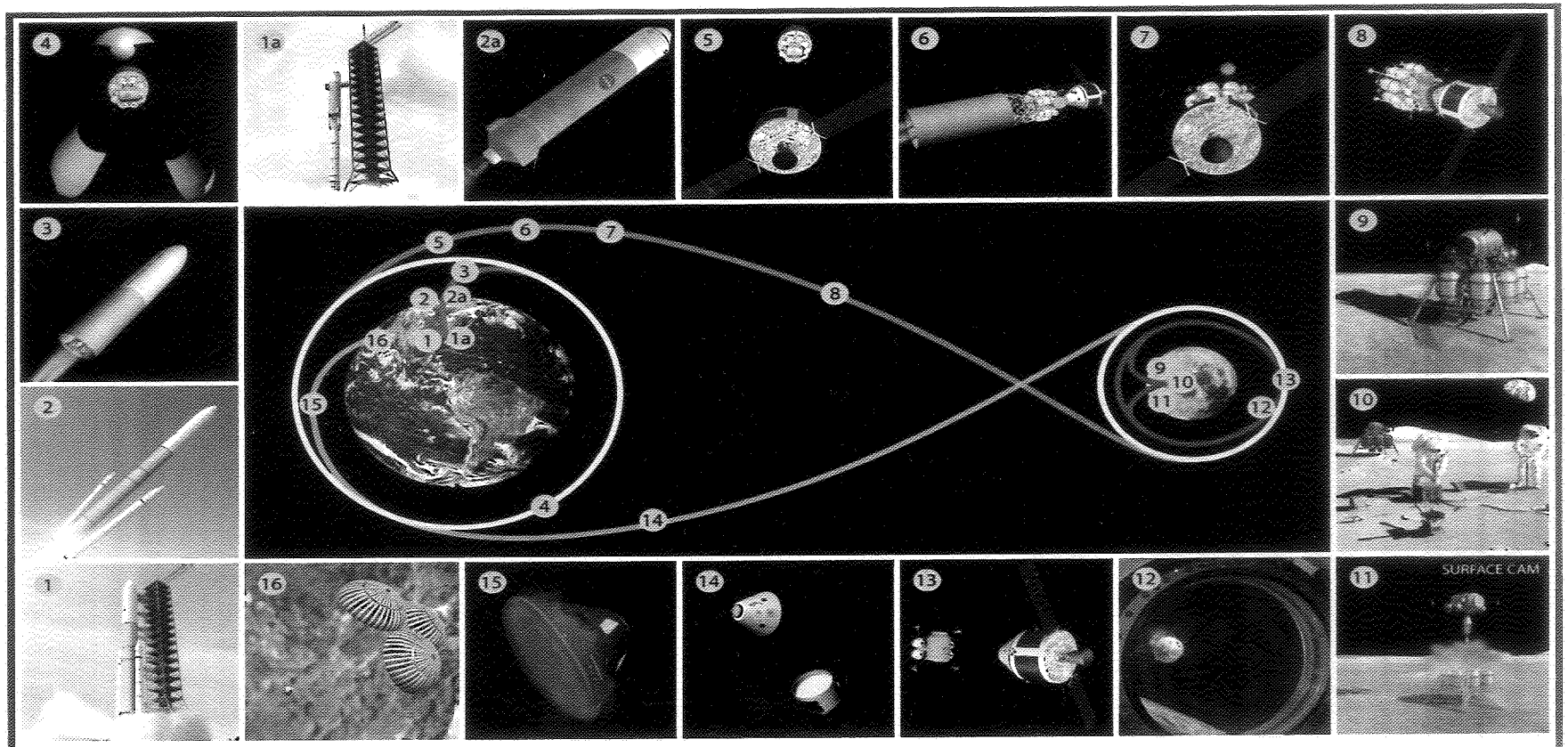
Crew Launch Vehicle Operational Concepts Document



- describes the manufacturing and assembly and desired operational system characteristics and concepts
- provides the CLV Project and its supporting systems the basic operational concepts to perform the functional analysis that drives the development of requirements
- includes test plans for operational concepts for flight tests



CLV Operational Concepts Document

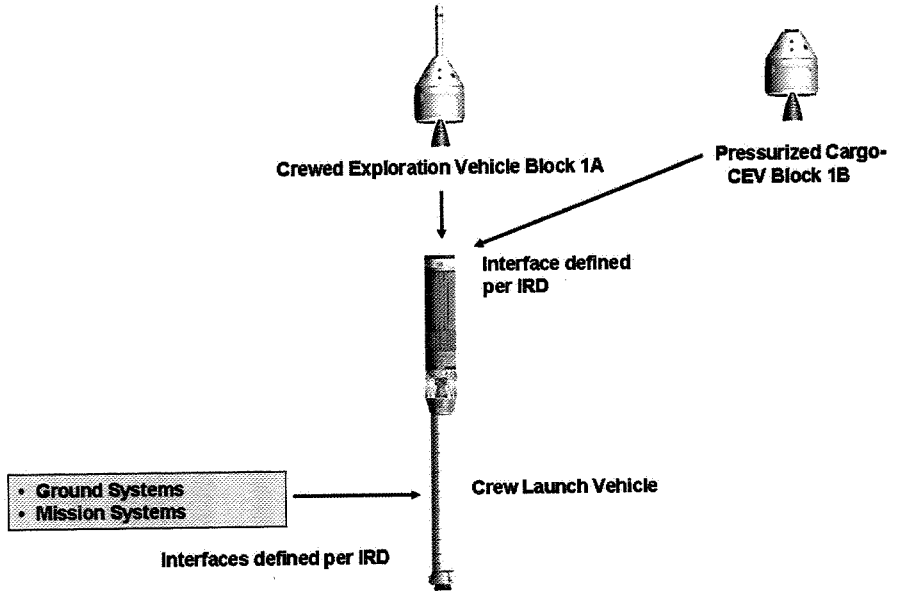


1. Cargo Launch Vehicle (CaLV) liftoff.
2. Solid Rocket Booster (SRB) separation.
3. Earth Departure Stage (EDS) fires for Earth orbit insertion.
4. Payload shroud separates to expose Lunar Surface Access Module (LSAM).

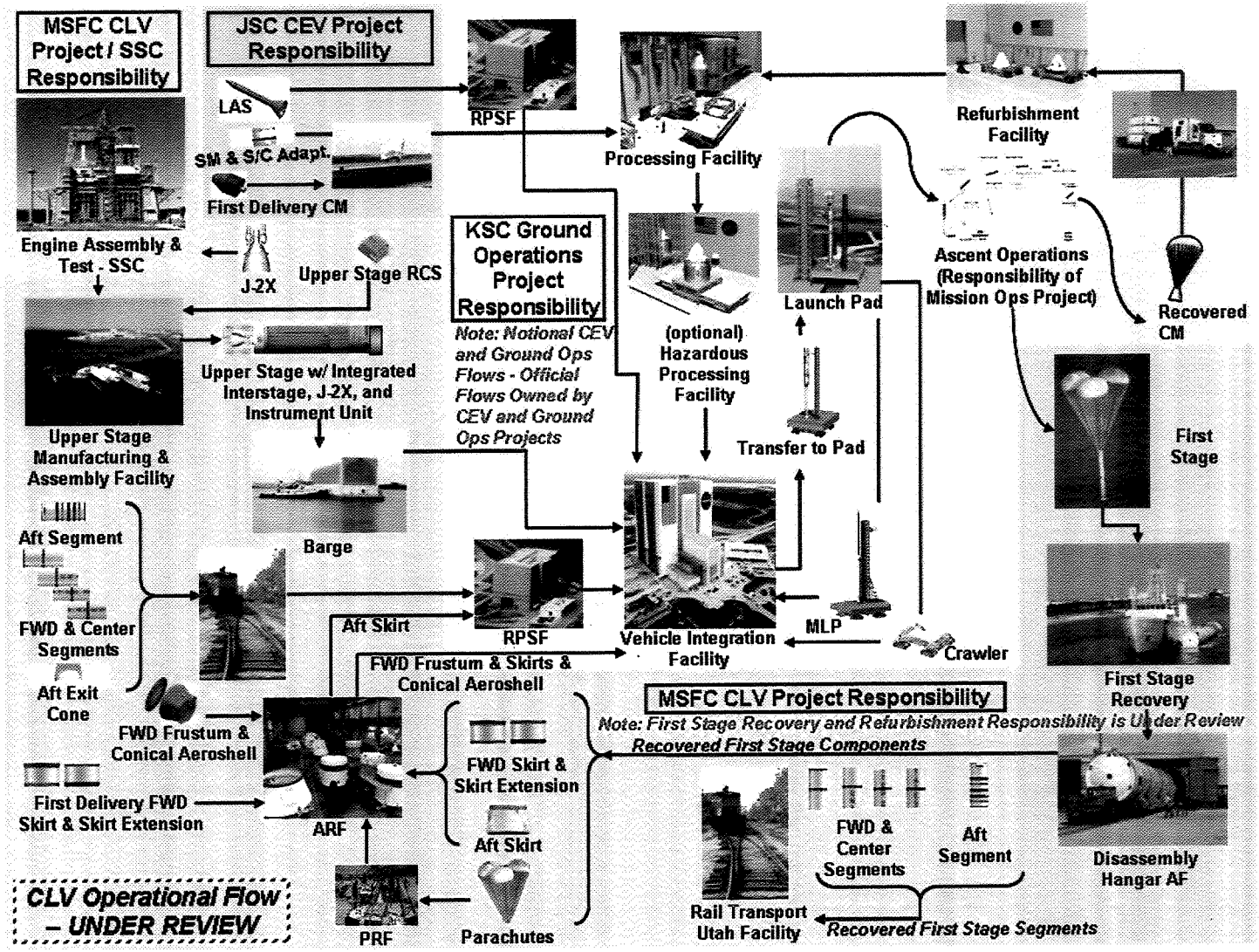
1a. Crew Launch Vehicle (CLV) liftoff.
2a. Upperstage fires for Earth orbit insertion.

5. Crew Exploration Vehicle (CEV) docks with LSAM and EDS.
6. EDS fires for lunar destination.
7. CEV and LSAM undock from EDS.
8. LSAM fires for lunar orbit insertion.
9. LSAM lands on lunar surface.
10. Conducting activities on the lunar surface.
11. LSAM ascent stage liftoff viewed from surface camera.
12. LSAM ascent stage prepares to dock with CEV.
13. LSAM ascent stage and CEV separate.
14. Capsule separates from service module.
15. Capsule reenters Earth's atmosphere.
16. Chutes open for landing and recovery in the Western U.S.

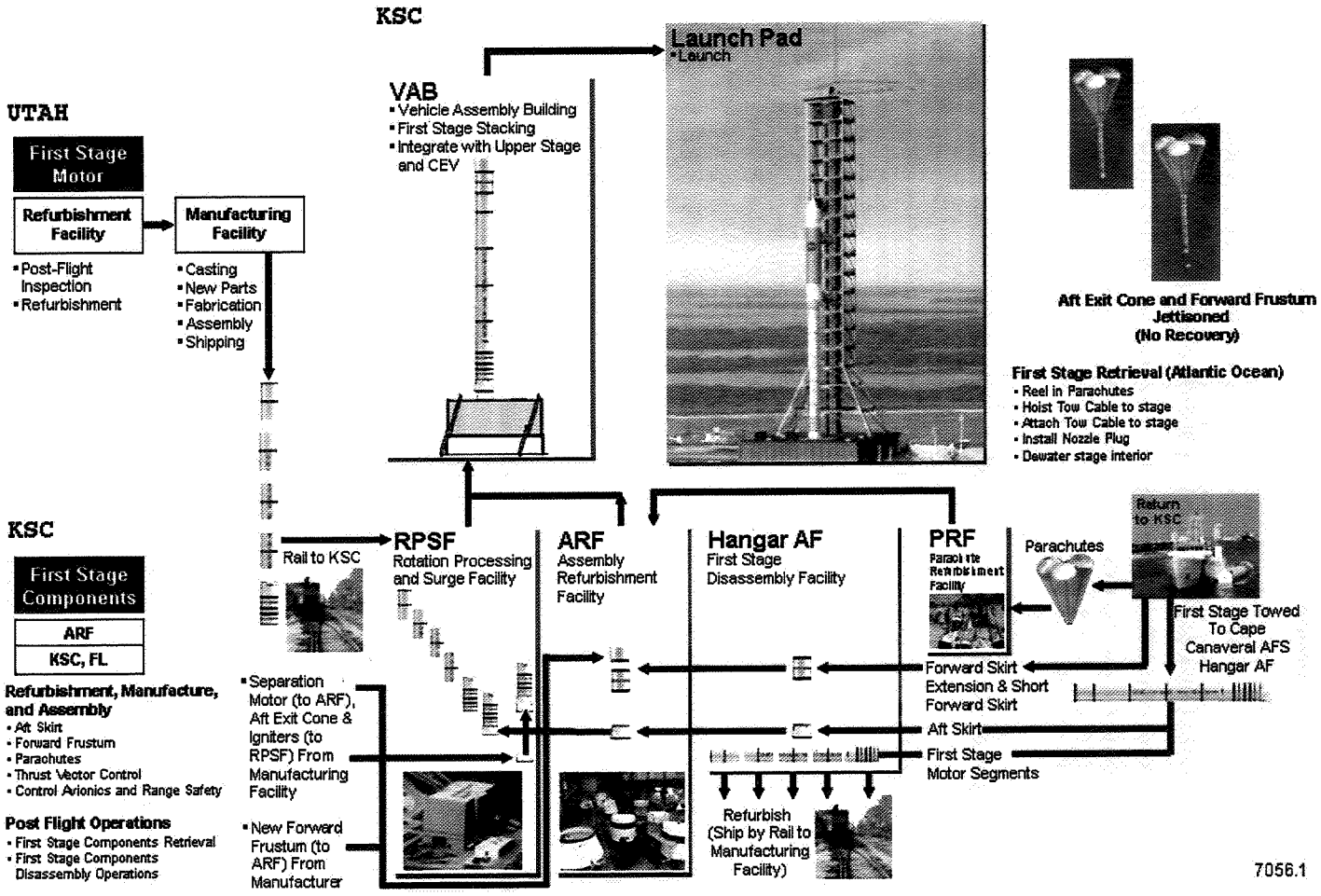
Constellation Systems Hierarchy



CLV Operational Flow Concept

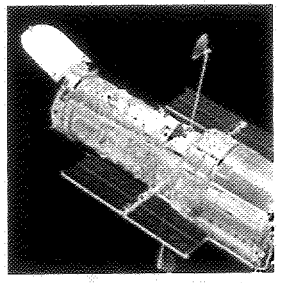


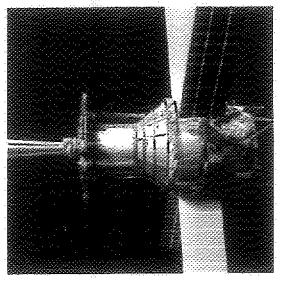
First Stage Assembly Flow

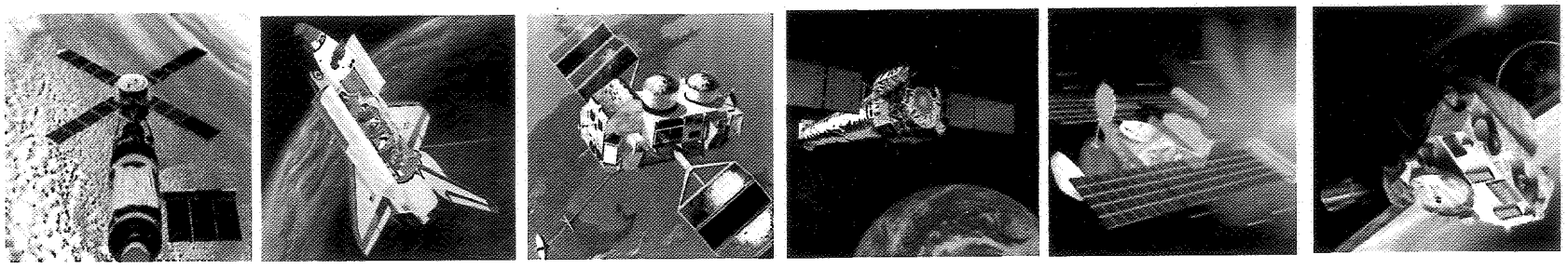


Conclusion

- NASA has used and will use many applications of Industrial Engineering and Systems Engineering to ensure safe and successful missions







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